Development and Evaluation of a Human Genetics Simulation Game for Classroom Instruction

An Honors Thesis (I.D. 499)

by

Jennefer K. Shockley

Thomas R. Mertens

Dr. Thomas R. Mertens

Thesis Director

Ball State University

Muncie, Indiana

May 1983

Table of Contents

Table of Figures

Development and Evaluation of a Human Genetics Simulation Game for Classroom Instruction

Jennefer Shockley

What is a game? According to Webster's dictionary, a game is a "sport of any kind; jest; play; some contrivance or arrangement for sport, recreation, testing skill, and the like."[1] However, there is another type of game that is not solely for entertainment and testing skill but serves to educate the player and allow him/her to develop skills.

These "educational" games for classroom use do have many similarities with games played for pleasure. According to Gordon, a game is "any simulated contest (play) among adversaries (players) operating under restraints (rules) for an objective (winning)."[2] It has therefore been established that a game must have three elements:[3]

(1) competition among players;

(2) clear cut method of determining a winner; and

(3) rules for playing the game.

However, if the game is to become an instructional game or simulation, it must meet further requirements. An instructional game must be "designed for helping the student learn something"[4], while a simulation is an "abstraction of some real-life object or event."[5]

Games serve as a successful classroom tool because they motivate both the students and the teacher. Games allow the teacher to

introduce variety into classroom work; at the same time, the elements of competition and the possibility of reward for success appeal to students. The student is allowed the opportunity to apply his/her knowledge to the given situation; the player can then see the results of the actions immediately. "Through the purposeful interaction, prompt and intrinsic feedback, realism and relevance of games students can become motivated to learn, realize the effect of value judgements, and analyze the basis for such judgements."[6]

Games allow for a number of benefits in the classroom. Games allow students of varied backgrounds or ability levels to interact on equal footing. Doran and Watson suggest that games provide the slow learner with an opportunity for success, while allowing the bright student to dig below the surface of a subject and investigate its basic structure and interactions.[7] Further benefits from games as reviewed by Doran and Watson are that "students can (1) be stimulated to go beyond the required materials of study, thereby expanding the scope of the curriculum, (2) understand better some of the seminal ideas of abstract, complex concepts, (3) learn that conceptual and factual knowledge is not only valuable in its own right, but even more valuable when used as a tool for reaching a goal."[8]

As with all educational tools, there are limitations to the use of games. Exaggerated competitiveness can lead to problems when a player takes losing too seriously. A second limitation can be encouragement of undesirable values such as competing to amass wealth, etc.[9] However, this can often be eliminated through discussion and analysis of actions directed by the teacher. A third limitation arises from the oversimplification of problems in the game.[10] Once again postgame

discussion can help to reduce this problem. Discussion can focus on the exceptions, qualifications, limitations and boundary conditions of the basic ideas learned from game play.[11]

The benefits of educational games and simulations appear to outweigh the limitations discussed. Games can provide an opportunity for students to "perform on a level above simple recall and recognition,"[12] while at the same time enjoying an alternate strategy of learning.

Developing the Genetics Game

History and Purpose

The human genetics game, The Gene Scene, was developed with two underlying goals: The first is to teach the players the basic principles of Mendelian genetics and the probability involved in the inheritance of autosomal dominant, autosomal recessive, and X-linked traits. Secondly, the game is designed to make the players aware of the emotional, ethical, and financial considerations which must be faced during genetic counseling. These two goals were then merged in the form of a board game designed to be of interest and educational value both to individuals with no prior knowledge of, or experience with, genetics and to individuals with previous education experience in the discipline.

Participation in The Gene Scene allows the player the opportunity to learn of some of the symptoms associated with the various diseases, the mode of inheritance of the disease, and the probabilities of having an affected child (depending on the genetic constitution of the parents). Furthermore, the player vicariously experiences genetic counseling and the cost of amniocentesis and prenatal diagnosis. By drawing "genotype cards" a player may be dealt an unwanted genotype, a situation not unlike what is experienced in real life. Furthermore, upon drawing a second "genotype card" for his/her spouse, the player may encounter, for example, a situation in which both husband and wife carry the same recessive gene. Subsequently, upon the roll of the

"genotype dice", the player may experience "producing" a child having a genetic disease such as cystic fibrosis. Such situations help the player to grasp the role of probability or chance in determining one's genetic constitution, health, and economic well-being. A "morals card", which the player may be instructed to draw at various points in the game, may impose certain moral constraints that affect how the player uses knowledge gained from "genetic counseling cards". The game, thus, affords players the opportunity to expand their genetic knowledge and to determine how new knowledge in genetics interfaces with societal concerns.

Components of the Game

The Gene Scene was developed as a board game for two to four players. There are numerous components necessary for playing the game including the board, genotype cards, genetic counseling cards, morals cards, child record cards, numeral dice, genotype dice, money, and moving pieces. Each of these will be discussed, beginning with the board.

The Board. The Gene Scene board serves two very important functions during play of the game. The board serves as the location of all the game "action" which takes place. It also serves as the source of information necessary for moving through the game successfully.

The board (Figure 1) was developed with these two purposes in mind. A geometric shape pleasing to the eye was chosen in hopes of drawing the attention of the players. However, the geometric shape was also designed to serve in dispensing information. The board

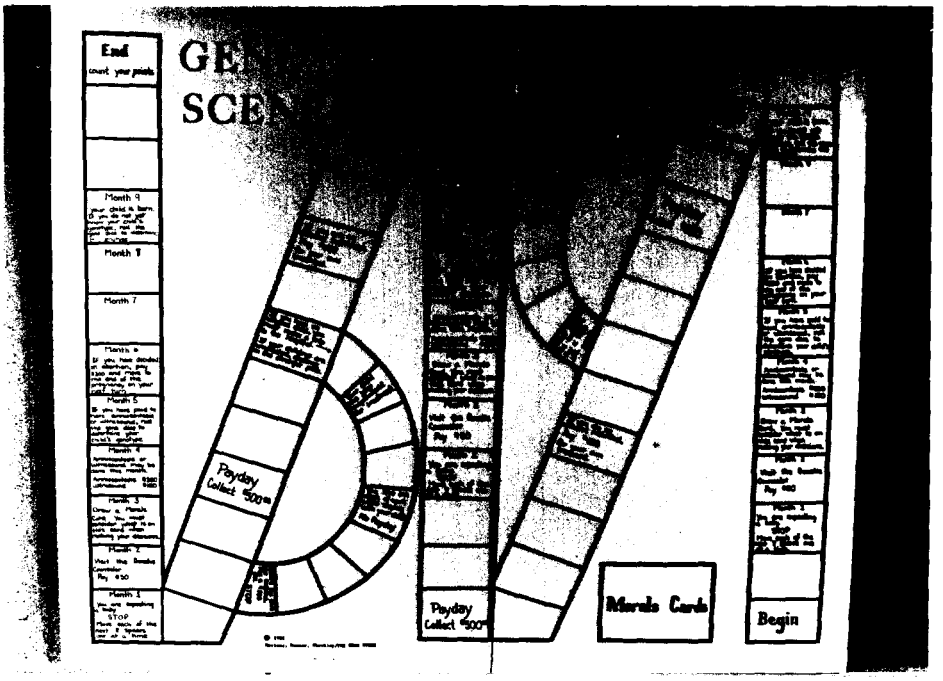

Figure 1. The Gene Scene game board.

appears as three parallel vertical strips which are joined by two diagonal strips. There is also a semi-circular unit adjoined to each diagonal strip. Each of these strips and units is divided into squares which serve as the units along which a player moves, and particular squares contain the information/directions for play.

The game action involves three pregnancies which are outlined in the three vertical strips of the board. Each pregnancy is broken into nine squares with each square representing one month of the nine month pregnancy. The first month informs the player that he/she and his/her spouse are expecting a child and from this point through month 9 the player should move one square each turn. The second month instructs the player to visit the genetic counselor. At this point the player is shown the Genetic Counselor Card for the trait in question; discussion of these cards will appear later. The third month instructs the player to draw a morals card which contains information which the player must consider when proceeding through the pregnancy. The following month the player is faced with the choice of whether or not methods of prenatal detection should be used. The options available include amniocentesis ($300) and ultrasound ($150) which can be done alone or in combination. While the fee is paid in this fourth month, it is not until the fifth month that the results are obtained. The fifth month directs the player to roll the genotype dice to determine the child's genotype if amniocentesis has been done. The next month provides the player with the option to abort the fetus. While the sixth month may seem to be too late to perform an abortion, it is necessary that it be this late if the results of amniocentesis are required before a decision can be made. If abortion is chosen, the

player is instructed to pay and move to the end of the pregnancy. If abortion is not chosen, the player takes no action during this month. Months seven and eight contain no instructions for the player and are inserted solely for the purpose of making the pregnancy a realistic nine months. While no action is taken during these months, the player continues to move one square per turn. Finally, month nine instructs the player to roll the genotype dice to determine the child's genotype if it is not already known. This then completes the first vertical strip, and the player continues "down" a diagonal strip of the board. The squares on the diagonal strip are relatively free of instruction with the exception of "Payday" squares which allow a player to collect $500 when passed and a square instructing an affected player to pay $150 for his/her own treatment. Also along this diagonal strip is the semi-circular loop which constitutes a trip to the hospital. If a player has an affected child, he/she is instructed to move through the squares on the loop. However, if the child is normal or if there is no child, the player may continue along the diagonal.

The hospital visit was added to the board in order to make the players more aware of the medical needs of an affected child. While proceeding through this loop, the player is advised that he/she has missed a payday due to work missed while caring for the child. Also before leaving the hospital the player is instructed to stop to pay a $300 hospital bill before proceeding. This loop causes the player to be affected monetarily and to be "slowed down" by additional squares, consequences similar to those suffered by parents of affected children in real life situations. Upon completion of the trip to the hospital, the player reenters the diagonal strip and continues play along with the other players.

The diagonal strip ends as a turn is made, and play continues up the second vertical strip containing the second pregnancy. This then leads into the second diagonal strip and hospital loop followed by the third pregnancy on the final vertical strip of the board. These sections of the board are identical to their counterparts discussed before. The board and the game then conclude with a square instructing the players to count their points to determine the game winner. This concludes the discussion of the board; however, there are several other components necessary for playing the game.

Genotype Cards. There are four different types of cards which become involved in play of the game: genotype cards, genetic counseling cards, morals cards and child record cards. The genotype cards (Figure 2) are distributed randomly once the player has selected a trait for playing the game; this is prior to the start of the game. There are eight genotype cards for each trait; each card shows a genotype, i.e., AA, Aa, or aa. Each player randomly draws two such cards; one card represents the genotype of the player, and the second card represents the genotype of the spouse. Much as in life, the player has no choice in what genotype he/she is given.

Genetic Counseling Cards. The genetic counseling cards (Figure 3) are referred to for all information regarding the description of the trait, its symptoms and consequences, the meaning attached to the genotypes of the trait, all the possible genetic crosses and the products of these crosses, and a listing of the possible methods of prenatal detection and the cost of such methods. The back of the genetic counseling card (Figure 4) also contains further information on the trait and its detection, frequency and treatment. There are nine

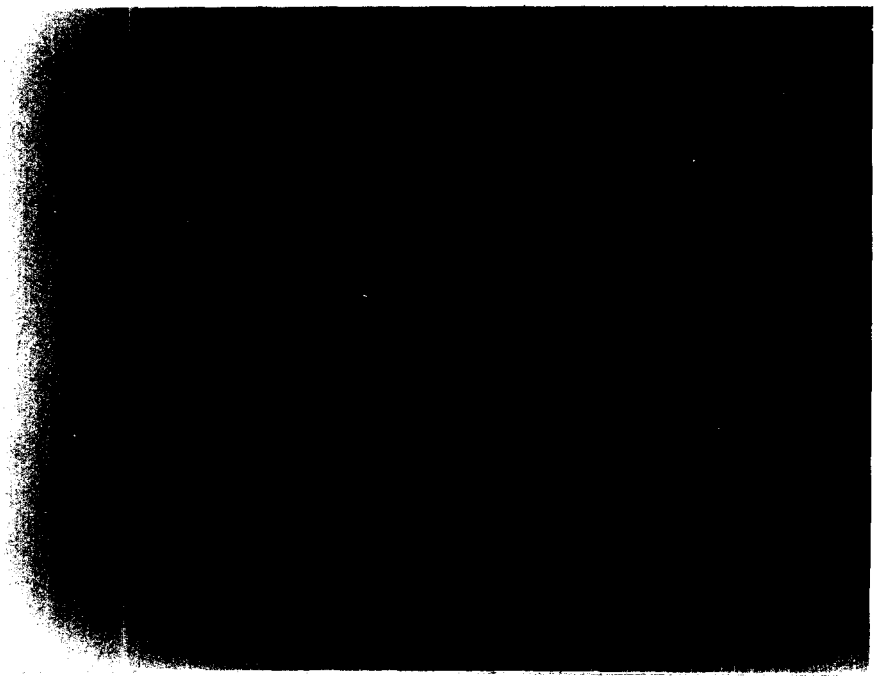

Figure 2. Genotype cards for the trait anchondroplasia. Each player draws two genotype cards, one to represent the genotype of the player and one to represent the genotype of his/her spouse.

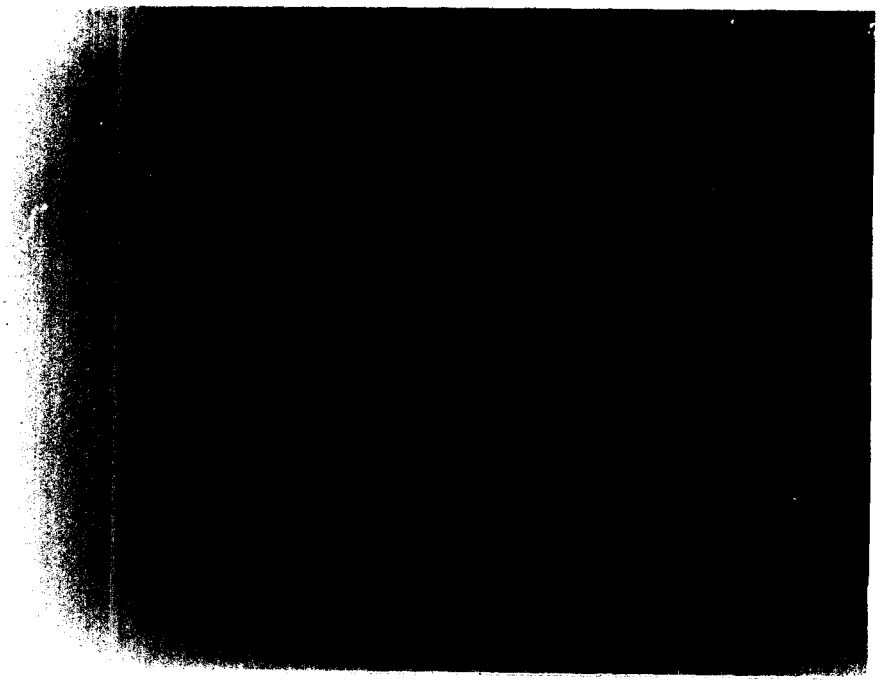

Figure 3. Genetic Counseling Card for the dominant trait achondroplasia. This figure shows the front of the card with a short description of the trait, explanation of genotypes, prenatal detection and the genetic crosses which may occur.

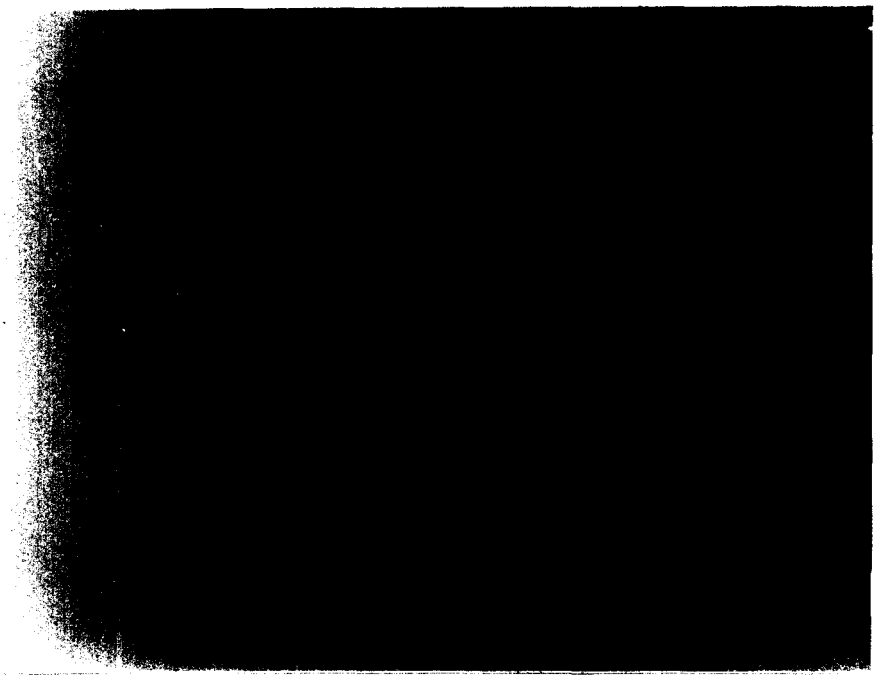

Figure 4. Genetic Counseling Card for the dominant trait achondroplasia. This figure shows the back of the card with additional information pertaining to the trait.

genetic counseling cards; one card for each trait available for play in the game. These cards are referred to when the player is directed to visit the genetic counselor. The cards were designed with information similar to the information that would be obtained upon an actual visit to the genetic counselor.

Morals Cards. A morals card is drawn during the third month of each pregnancy and presents the player with a "situation" which must be considered while proceeding through the pregnancy. Each morals card is designed to make the player aware of some of the "hidden" and yet very important aspects of decision making. The morals cards include such situations as...

> "Your religion will not allow for an abortion. This is not an option for you."
>
> "There are no medical facilities for amniocentesis. This is not an option for you."
>
> "Conflict with spouse over amniocentesis and abortion. Lose a turn making a decision."
>
> "Family does not want you to have an abortion. Make your own decision. Lose a turn."
>
> "You do not believe in amniocentesis or abortion. These are not options for you."
>
> "You have faith in yourself and feel you can make a wise decision."

Child Record Cards. The child record cards (Figure 5) are used to record the genotype and phenotype of each child as it is determined. They play no essential role in the game; the record card is only for the convenience of the player.

Gene Dice. The gene dice are essential for determining the genotype of each child. There are four types of gene dice. The first

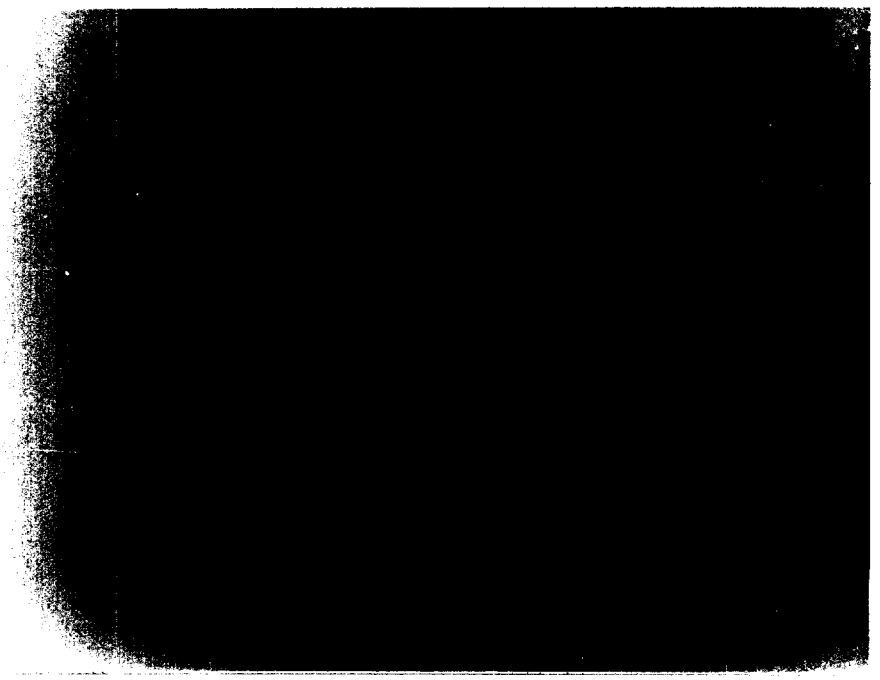

Figure 5. Child Record Cards are used to assist the player in keeping a record of each child born, the child's genotype, and the child's phenotype. These recordings can be made using wax pencil and then erased following completion of the game.

is a die with all six sides showing the large "A" gene which corresponds to a AA genotype card. The second die shows all six sides as small "a" genes corresponding to a aa genotype card. There is also a gene die corresponding to the Aa genotype card which has three sides showing the large "A" gene and three sides showing the small "a" gene. Finally, there is a die which corresponds to the male genotype AY (for an X-linked trait) with three sides showing the large "A" gene and three the "Y" chromosome. The proper gene dice corresponding to the player's genotype cards are selected and rolled in order to determine the child's genotype. The roll of the dice was selected as the method for determining the child's genotype because the random throw of the dice is similar to the random assignment of genes in real life situations. It should also be noted that the probability of the die assigning a particular gene is identical to a child actually receiving a particular gene from his/her parents.

Numeral Dice. The game also includes four numeral dice. Each player receives a numeral die to be rolled to determine the number of spaces to be moved during each turn. There is an exception to this in the case of the nine months of each pregnancy where the die is not rolled; during a pregnancy each turn a player moves only one square.

Other components. Another component of the game is a bank containing various denominations of money to be distributed to the players at the beginning of the game and when they pass "payday". The money is used by the players to pay their bills. Finally, there are "cars" which serve as pieces for the players to move around the board, each player having a "car" to mark his/her location on the board.

Traits Used in Playing the Game

There are nine traits available for play in The Gene Scene. These traits are either autosomal recessive, autosomal dominant or X-linked recessive traits. The player has the opportunity to learn some of the symptoms associated with the diseases, how the diseases are inherited, the detection and treatment involved with the diseases, and the probabilities of having an affected child.

The autosomal recessive traits included are cystic fibrosis, phenylketonuria (PKU), sickle cell anemia, and Tay-Sachs disease. Autosomal dominant traits include achondroplasia, hypercholesterolemia, and Marfan's syndrome. Duchenne muscular dystrophy and hemophilia are utilized as the X-linked traits.

Cystic Fibrosis (CF) is a simple recessive trait which is present in a child at the time of birth. The major medical problems related to cystic fibrosis are caused by abnormal secretion of mucus that obstructs the ducts of internal organs. The lungs, pancreas, intestine, and liver are often affected. About three quarters of the affected persons who live beyond the first year of life live to be fifteen or twenty[13] years old; however, death eventually results, usually due to lung disease.

There is no cure for cystic fibrosis at this time. Treatment involves therapy to clear mucus from ducts of the lungs along with antibiotic and vitamin therapy.

Cystic fibrosis occurs with greatest frequency in the white population among whom the frequency of affected children is about 1/2000[14] births. Although cystic fibrosis can be detected prenatally,

most often it is not detected until birth.[15] In families with a known history of cystic fibrosis, prenatal detection can be useful, but many CF children are born in families with no such history and therefore no reason for prenatal testing for CF.

At this time there is no consistently accurate method for identifying carriers of CF. However, parents who have a child with CF have a 25% risk for each subsequent pregnancy.

Phenylketonuria (PKU) is a simple recessive trait which is present in a child at the time of birth; however, the child still appears "normal." The only consistent symptom occurring during the first month of life is the accumulation of excess phenylalanine in the blood. PKU eventually leads to profound neurological disturbances and severe mental retardation. Due to a lack of an enzyme normally produced in the liver, the amino acid phenylalanine cannot be broken down by the body. High levels of phenylalanine can then cause brain damage.

There is no cure for PKU. However, a child identified at birth as having PKU can be placed on a special low phenylalanine diet. If this is done, the child will not exhibit the severe effects of the disease.

PKU occurs with the greatest frequency in certain northern European populations such as Irish, Scotch and Scandinavians and their descendents.[16] Among these populations the frequency of affected children is about 1/11,000 births.[17] The frequency of PKU in the U.S. white population is about 1/15,000 births.[18]

At this time, PKU cannot be detected prenatally. In most states, after the birth of the child, a smear of blood is taken; this blood is then analyzed for excess phenylalanine. A child showing an excess level is diagnosed as having PKU, and treatment may begin.

There is also no method for accurately identifying carriers of the disease. Parents who have had a child with PKU have a 25% risk for each subsequent pregnancy.

Sickle Cell Anemia is also a simple recessive trait. Persons affected with the disease have sickle shaped red blood cells which cannot pass through small blood vessels easily. This blocks the flow of oxygen to certain tissues, causing the person to experience shortness of breath, pain in the arms, legs, back and abdomen, swollen joints and the possibility of death from lack of oxygen.

Currently there is no cure for sickle cell anemia either. The best treatment is prevention of the attacks of sickling -- reduce the hazard of an attack by avoiding low oxygen conditions. Drugs that prevent or reduce sickling are being studied at this time.

Sickle cell anemia occurs with greatest frequency in the black population among whom the frequency of affected children is about 1/500 births.[19]

Using recently developed techniques, sickle cell anemia can be detected in the fetus following amniocentesis[20, 21, 22] and the analysis of fetal cells from the amniotic fluid. Carriers of the sickle cell gene can also be identified using a fairly simple test. Once a man and woman are aware that they both carry the gene for sickle cell anemia, a genetic counselor can explain their chances of having a baby with the disease.

Tay-Sachs disease is the final recessive trait available for play in the game. Symptoms of Tay-Sachs appear about six months after birth and are characterized by degeneration of the nervous system. The child first becomes blind, followed by loss of intellectual

capabilities, progressive muscular weakness and paralysis. The child usually dies by the age of three to four years. At this time there is no cure for Tay-Sachs disease; there is no treatment available for affected children either.

Tay-Sachs disease occurs with the greatest frequency in Jewish people of Eastern European descent. Among this population the frequency of children affected with the disease is about 1/4000-6000 births.[23] Among the non-Jewish population the frequency of Tay-Sachs is about 1/500,000 births.[24]

Tay-Sachs disease can be detected in the fetus using amniocentesis followed by analysis of fetal cells obtained from the amniotic fluid.[25, 26, 27, 28] Carriers of the Tay-Sachs gene can also be identified using a simple test.

Achondroplasia is a dominant trait. It is a familiar type of dwarfing in which the long bones do not develop properly. As a result, the individual is unusually short. The affected person may also suffer from a bulging skull, small rib cage, and changes in the spine and hip region. While some of those affected die at an early age, many achondroplasic people lead a "normal" life.

There is currently no cure or treatment for achondroplasia. Achondroplasia is said to occur in approximately 1 in 10,000 live births.[29] However, this may be inaccurate due to lack of differentiation between forms of dwarfism.

Achondroplasia can be detected in the fetus using a simple ultrasound test. The ultrasound test will allow detection of abnormal body measurements in the fetus.[30, 31] As is generally true of all

dominant traits, either the husband or wife or both must be affected with achondroplasia to have an affected child.

Hypercholesterolemia is also a dominant trait. It appears sometime in early childhood and is characterized by extremely high levels of cholesterol in the body. Physical symptoms include yellowish lumps found on the knees, elbows and hand tendons and high levels of cholesterol in the blood. It is this high level of cholesterol in the blood which leads to early heart attack and death in those affected. Persons with two defective genes usually live to only their early twenties. Persons with only one defective allele may live to be thirty or forty years old.

Hypercholesterolemia cannot be cured at this time, but it can be treated with special diet or drug therapy. This disease occurs with equal frequency among all racial and ethnic groups. The frequency of hypercholesterolemia is estimated to be as high as 1/500 births.[32]

Hypercholesterolemia can be detected in the fetus using amniocentesis followed by analysis of cells from the amniotic fluid.[33] In order for a child to have the disease, one or both of his parents must also have the disease.

Marfan's syndrome is the third dominant trait available in the game. Marfan's syndrome is characterized by unusually long legs, arms and fingers. The affected person often suffers from abnormalities of connective tissue formation leading to defects of the heart. There are also some complications with respiration and eye sight in the affected person.

There is currently no cure or treatment for Marfan's syndrome. However, the occurrence of Marfan's syndrome is very rare and only appears in about 1 in 66,000 births in most populations.[34]

There is also no current method for detecting Marfan's syndrome in the fetus. It is generally necessary that either the mother or father or both have Marfan's syndrome to have an affected child.

Duchenne muscular dystrophy is one of the two X-linked recessive traits which are available to be used in playing The Gene Scene. Symptoms of Duchenne muscular dystrophy appear in the child between the ages of one and six years and are characterized by degeneration of the muscles. Muscle weakening continues, and the child is usually confined to a wheelchair by the age of nine to twelve years. Three fourths of the victims die by the age of twenty, usually by failure of the heart or respiratory muscles.

Treatment of this disease usually involves making the patient comfortable and aleviating symptoms, but at this time there is no cure for Duchenne muscular dystrophy. The disease is rarely found in females. However, the frequency of affected males is about 3/10,000 births.[35]

Duchenne muscular dystrophy has been detected in the fetus using amniocentesis.[36, 37] It is also possible to identify women who carry the gene using an enzyme test.

Hemophilia is also an X-linked recessive trait. Classical hemophilia is characterized by internal bleeding, especially in the joints. It is this bleeding which may lead to the crippling deformities associated with hemophilia.

There is no cure for hemophilia. However, it can be treated by providing the missing factor needed for clotting of the blood to occur. Because hemophilia is an X-linked trait, it rarely appears in females, but occurs in about 1 in 10,000 male births.[38]

Hemophilia has been detected in the fetus using a combination of procedures.[39, 40, 41] Amniocentesis is performed to determine the sex of the fetus. If it is a male, a second procedure is used to obtain a sample of fetal blood. This sample can then be analyzed for the missing factor to determine if the child has hemophilia. It is also possible to identify women who carry the gene for hemophilia.

These nine traits were selected for the game in order to provide a variety of autosomal recessive, autosomal dominant and X-linked traits and to provide both variety and "excitement" for the player. Utilizing different traits, a player may play the game many times without ever actually playing the same game twice. For example, he/she might use an autosomal dominant trait such as Marfan's syndrome, and the next time might select hemophilia, an X-linked recessive trait. This allows the student to increase his/her knowledge by "experiencing" all nine traits at various times.

Playing the Genetics Game

Before game play begins, the board must be set up and each player prepared (Figure 6). The board requires only minimal preparation. The morals cards are to be shuffled and placed on the designated position on the board. The "cars", containing a "husband and wife" which serve as the moving pieces for each player, are placed on the square marked "Begin". Next, a trait or traits must be chosen for play. Once the selection is made, each player draws two genotype cards for each trait that is being used in that particular game. One card specifies the husband's genotype; the other specifies the genotype of the wife for the trait under consideration. If the game is being played by advanced players utilizing more than one trait, each player should draw a pair of genotype cards for each trait being used. Finally, each player is given a numeral die and $1000 in game money. Following this preparation, playing of The Gene Scene may begin.

To begin playing The Gene Scene each player rolls his/her die and moves the rolled number of spaces or until he/she reaches the location on the board marked "Stop". The first "Stop" occurs on the third space of the board and indicates the beginning of a pregnancy. The player reads the instructions given on the square indicated as "Month One" of the pregnancy. With each succeeding turn the player moves one square until he/she reaches the ninth month of the pregnancy.

Figure 6. Three Biology 199 students, Sierra Rogers, Vickie Shaw and Jane Puetz, playing The Gene Scene.

Each month contains self-explanatory instructions for the player to follow; these instructions have been outlined in the previous discussion of the board. Following completion of this first pregnancy, the player again rolls the numeral die and continues along the board for the number of spaces determined by the roll of the die. The player will be required to move around the hospital loop if he/she has an affected child. Otherwise, the player will continue relatively uneventfully to the next "Stop" on the board, through this pregnancy and on through the third pregnancy following all instructions outlined on the board. It should be noted that a player only needs to pass a payday in order to collect his/her $500.

As play progresses, the players move toward the end of the board. The game ends when all players have reached the space on the board that is marked "End". To determine the winner each player counts up his/her points as follows:

1. Each child the player has, whether it is an affected or normal child, is worth five points.

2. Each one hundred dollars the player has at the end of the game is counted as one point.

Each player counts up his/her points, and the player with the most points wins the game.

Testing the Genetics Game

In order to determine the educational value of The Gene Scene, a method of evaluating its effectiveness was developed. A pretest and parallel post test were first designed. The test consisted of twenty questions concerning autosomal recessive, autosomal dominant and X-linked traits and included both recall type questions and problem-solving questions. The recall questions ask the player such items as, "In what month is amniocentesis ordinarily performed?" and "How long does it ordinarily take to get the results of amniocentesis?" A variety of these recall questions were intermixed with problem-solving questions asking the person, for example, to determine the probability of producing an affected child given two parental genotypes. The twenty questions of the pretest and post test are listed in Appendix A. The two tests utilized identical questions assembled in different orders.

The testing of the educational value of The Gene Scene was done utilizing freshman honors students from Biology 199. Volunteers from the class were randomly assigned to testing groups of two, three or four players. The evaluation then proceeded in three steps. The first step involved administering the pretest to the group. Then, one complete cycle of The Gene Scene was played using an autosomal recessive, an autosomal dominant and an X-linked trait. This allowed the players to be exposed to the methods of inheritance of all three types of traits. After playing the game, the third phase involved administering the post test to all the players.

The testing process was done over a period of two quarters involving two separate classes of Biology 199. A total of sixty-one students participated in the game testing. During the Fall Quarter 1982, thirty-two students participated. Winter Quarter 1982-83 provided an additional twenty-nine students. The data were gathered, then analyzed using a pairing design test. The raw data are provided in Appendix B, and the computed results are summarized in Table 1.

Analysis of the educational value of The Gene Scene was based upon the measure of improvement between pretest and post test scores of the participants. The data show that no person experienced a decline in his/her test score following the game, and only a few participants showed no improvement in their post test score. The majority of students improved their test performance after playing The Gene Scene.

In order to determine if this increase in performance was significant, a pairing design test was done; the t value was calculated for each experimental group and compared to a t critical value as read from a table of t values. All calculations are shown in Appendix B. At the .05 probability level, both testing groups showed a significant improvement in their post test scores. These results can be interpreted to mean that the probability of this level of improvement occurring by chance alone is less than five percent. These data would therefore lead to the conclusion that by playing The Gene Scene students can improve their performance on a post test involving problem solving and recall of factual information pertaining to human genetics. One may logically assume that The Gene Scene does indeed exhibit educational value by allowing students to expand their

knowledge of human genetics concepts. It is not by conventional methods that this advancement is achieved but by allowing the student to "experience human genetics" as it exists in day-to-day life.

Table 1. Analysis of testing results for The Gene Scene

	Group 1	Group 2
Number	32	29
Mean Score Pretest[1]	12.50	13.03
Mean Score Post test[1]	16.44	17.21
Mean Difference	3.94	4.17
Calculated *t* value	10.65	7.61
Degrees of Freedom	31	28
Critical *t* value[2]	2.04	2.05

[1]Number correct out of 20 possible

[2]Two-tailed *t* test at .05 probability level

Discussion and Conclusions

The Gene Scene was developed as a human genetics game to be used as a learning tool in the biology classroom. The board game consists of all the essential elements of a game: competition among players, clear cut method of determining a winner, and rules for playing the game.[42] The game is further considered a simulation because it is an "abstraction of some real-life object or event."[43] Therefore, The Gene Scene is a simulation game available for use as a learning tool.

The simulation game was designed to be of interest and educational value both to individuals with no prior knowledge of, or experience with, genetics and to individuals with previous educational experience in the discipline. From the testing experience, it is apparent that this goal has been achieved. Students from diversified backgrounds participated in the testing process, and all students provided favorable feedback. Representative comments from participants included:

> "The game was helpful and informative."
>
> "I enjoyed the game. Besides learning of genetic disorders, the problem was applied to each person."
>
> "The game we played was thought provoking, and it made me consider many things."
>
> "I enjoyed the game!"

The Gene Scene was developed with two underlying educational goals: The first is to teach the players the basic principles of Mendelian genetics and the probability involved in the inheritance of autosomal dominant, autosomal recessive, and X-linked traits. Secondly, the game is designed to make players aware of the emotional, ethical, and financial considerations which must be faced during genetic counseling.

Analysis of the testing data provides strong evidence that the first goal has been achieved. It would be very unlikely to obtain a statistically significant improvement in post test scores if the participants had not become familiar with the basic principles of Mendelian genetics and the probability involved in the three modes of inheritance. Achievement of the second goal is not so readily measured. However, because of the components built into the game, i.e., morals cards, decision-making, and payment using game money, the player is almost forced into awareness of the emotional, ethical, and financial considerations of genetic diseases and genetic counseling.

As previously stated, games can provide an opportunity for students to "perform on a level above simple recall and recognition,"[44] while at the same time enjoying an alternate strategy of learning. The Gene Scene serves as an alternate strategy for learning about human genetics; and it appears to be quite effective at its task.

Recommendations

After many months of developing and testing the human genetics game, The Gene Scene, there are three recommendations that I would suggest:

1. A pair of parallel tests should be developed and used as the pretest and the post test. A single test was used for this purpose in my testing efforts. The questions were identical; however, they were arranged in a different order for each test. It has been suggested that the time interval between administration of the two tests was too short (approximately one hour) to allow valid results to be obtained. This idea assumes that the student remembers many of the questions and looks for the answers to these questions while playing the game. I believe that the use of the same questions had only minimal effect on the testing results. I base this assumption on the fact that the majority of questions on the pretest/post test were of a problem-solving nature. It would be somewhat more difficult for a game participant to memorize the responses to these questions. The student must comprehend the concepts in order to solve this type of question. For this reason, I believe the testing results to be valid. However, it would be beneficial to repeat the testing process using

parallel but not identical test questions on the pretest and post test.

2. A computerized version of The Gene Scene should be developed for use with a microcomputer such as the Apple II. This recommendation results from comments made by representatives of biological supply companies which were contacted to find one interested in marketing The Gene Scene. The response of many of these companies was that the game was very interesting and had evident educational value, but board games are becoming obsolete as computer games gain ascendency. Thus, my second recommendation is to develop a computer version of The Gene Scene. (I would like to add that The Gene Scene has now been developed into a game for microcomputer. This project was completed through the hard work of Mike Hassing, a computer science master's degree candidate.)

3. Another outside reviewer suggested that the method used in determining the winner of the game may result in fostering undesirable values such as competing to amass wealth. This criticism may well be valid; this problem is often cited as a weakness with educational games.[45] Consequently, a new and educationally sound method of determining the game winner should be developed. This new method of scoring should reflect the amount of knowledge gained by the player rather than the amount of money accumulated during play. (In fact, a new method of determining the winner will be incorporated into the computerized version of the game.)

End Notes

1. Thatcher, V.S. ed. 1971. The New Webster Dictionary of The English Language. Consolidated Book Publishers. Chicago. p. 357.

2. Gordon, A.K. 1970. Games for Growth. Science Research Associates. Palo Alto, CA.

3. Thiagarajan, S. 1974. "Gamegame II." Phi Delta Kappan 55:474.

4. ibid.

5. ibid.

6. Doran, R.L. and W. Watson. 1973. "Games for the Science Classroom." The Science Teacher 40:31.

7. ibid.

8. ibid.

9. ibid.

10. ibid.

11. ibid.

12. ibid.

13. Novitski, E. 1982. Human Genetics, Second Edition. Macmillan Publishing Co. New York. p. 86.

14. ibid. p. 85.

15. Nadler, H.L. and M.M.J. Walsh. 1980. "Intrauterine Detection of Cystic Fibrosis." Pediatrics 66:690.

16. Novitski, p. 89.

17. ibid.

18. Bergsma, D. ed. 1979. Birth Defects Compendium, Second Edition. Alan R. Liss, Inc. New York. p. 866.

19. Novitski, p. 87.

20. Alter, B.P., C.B. Modell, and D. Fairweather. 1976. "Prenatal Diagnosis of Hemoglobinopathies: A Review of 15 Cases." New England Journal of Medicine 295:1437.

21. Panny, S.R., A.F. Scott, and J.A. Phillips. 1979. "Prenatal Diagnosis of Sickle Cell Disease by Restriction Endonuclease Analysis: Limitations and Advantages." American Journal of Human Genetics 31:58A.

22. Phillips, J.A., A.F. Scott, H.H. Kazazian, Jr., K.D. Smith, G. Stetten, and G.H. Thomas. 1979. "Prenatal Diagnosis of Hemoglobinopathies by Restriction Endonuclease Analysis: Pregnancies at Risk for Sickle Cell Anemia and S-O Arab Disease." Johns Hopkins Medical Journal 145:57.

23. Novitski, p. 86.

24. ibid.

25. O'Brien, J.S., S. Okada, and D.L. Fillerup. 1971. "Tay-Sachs Disease: Prenatal Diagnosis." Science 172:61.

26. Saifer, A., L. Schneck, G. Perle, C. Balenti, and B.W. Volk. 1973. "Caveats of Antenatal Diagnosis of Tay-Sachs Disease." American Journal of Obstetrics and Gynecology 115:553.

27. Navon, R. and B. Padeh. 1971. "Prenatal Diagnosis of Tay-Sachs Genotypes." British Medical Journal 4:17.

28. Wyatt, P.R. and D.M. Cos. 1977. "Utilization of Electron Microscopy in the Prenatal Diagnosis of Genetic Disease." Human Heredity 27:22.

29. Hartl, D.L. 1983. Human Genetics. Harper and Row, Publishing, Inc. New York. p. 87.

30. Leonard, C.O., R.C. Sanders, and H.L. Lau. 1979. "Prenatal Diagnosis of the Turner Syndrome, a Familial Chromosomal Rearrangement and Achondroplasia by Amniocentesis and Ultrasonograph." Johns Hopkins Medical Journal 145:25.

31. Russell, J.G.B. 1973. Radiology in Obstetrics and Antenatal Pediatrics. Butterworths. London.

32. Bergsma, p. 541.

33. Brown, M.S., J.L. Goldstein, and K. Vandenberghe. 1978. "Prenatal Diagnosis of Homozygous Familial Hypercholesterolemia: Expression of a Genetic Receptor Disease in Utero." Lancet 1:526.

34. Bergsma, p. 681.

35. Novitski, p. 142.

36. Mahoney, M.J., F.P. Haseltine, J.C. Hobbins, B.Q. Banker, T. Caskey, and M.S. Golbus. 1977. "Prenatal Diagnosis of Duchenne's Muscular Dystrophy." New England Journal of Medicine 297:968.

37. Golbus, M.S., J.D. Stephens, and M.J. Mahoney. 1979. "Failure of Fetal Creatine Phosphokinase as a Diagnostic Indicator of Duchenne Muscular Dystrophy." New England Journal of Medicine 300:860.

38. Novitski, p. 141.

39. Firshein, S.I., L.W. Hoyer, and J. Lazarchick. 1979. "Prenatal Diagnosis of Classic Hemophilia." New England Journal of Medicine 300:937.

40. Mibashan, R.S., J.K. Thumpston, and J.D. Singer. 1979. "Plasma Assay of Fetal Factors VIIIC and IX for Prenatal Diagnosis of Hemophilia." Lancet 1:1309.

41. Mibashan, R.S., I.R. Peuke, and S.H. Rodeck. 1980. "Dual Diagnosis of Prenatal Hemophilia A by Measurement of Fetal Factor VIIIC and VIIIC Antigen (VIIIC ag)." Lancet 2:994.

42. Thiagarajan, p. 474.

43. ibid.

44. Doran and Watson, p. 31.

45. ibid.

Bibliography

Alter, B.P., C.B. Modell, and D. Fairweather. 1976. "Prenatal Diagnosis of Hemoglobinopathies: A Review of 15 Cases." New England Journal of Medicine 295:1437.

Bergsma, D. ed. 1979. Birth Defects Compendium, Second Edition. Alan R. Liss, Inc. New York, New York.

Brown, M.S., J.L. Goldstein, and K. Vandenberghe. 1978. "Prenatal Diagnosis of Homozygous Familial Hypercholesterolemia: Expression of a Genetic Receptor Disease in Utero." Lancet 1:526.

Doran, R.L. and W. Watson. 1973. "Games for the Science Classroom." The Science Teacher 40(4):31.

Firshein, S.I., L.W. Hoyer, and J. Lazarchick. 1979. "Prenatal Diagnosis of Classic Hemophilia." New England Journal of Medicine 300:937.

Golbus, M.S., J.D. Stephens, and M.J. Mahoney. 1979. "Failure of Fetal Creatine Phosphokinase as a Diagnostic Indicator of Duchenne Muscular Dystrophy." New England Journal of Medicine 300:860.

Gordon, A.K. 1970. Games for Growth. Science Research Associates. Palo Alto, California.

Hartl, D.L. 1983. Human Genetics. Harper and Row, Publishing, Inc. New York, New York.

Leonard, C.O., R.C. Sanders, and H.L. Lau. 1979. "Prenatal Diagnosis of the Turner Syndrome, a Familial Chromosomal Rearrangement and Achondroplasia by Amniocentesis and Ultrasonograph." Johns Hopkins Medical Journal 145:25.

Mahoney, M.J., F.P. Haseltine, J.C. Hobbins, B.Q. Banker, T. Caskey, and M.S. Golbus. 1977. "Prenatal Diagnosis of Duchenne's Muscular Dystrophy." New England Journal of Medicine 297:968.

Mibashan, R.S., J.K. Thumpston, and J.D. Singer. 1979. "PLasma Assay of Fetal Factors VIIIC and IX for Prenatal Diagnosis of Hemophilia." Lancet 1:1309.

Mibashan, R.S., I.R. Peuke, and S.H. Rodeck. 1980. "Dual Diagnosis of Prenatal Hemophilia A by Measurement of Fetal Factor VIIIC and VIIIC Antigen (VIIIC ag)." Lancet 2:994.

Nadler, H.L. and M.M.J. Walsh. 1980. "Intrauterine Detection of Cystic Fibrosis." Pediatrics 66:690.

Navon, R. and B. Padeh. 1971. "Prenatal Diagnosis of Tay-Sachs Genotypes. British Medical Journal 4:17.

Novitski, E. 1982. Human Genetics, Second Edition. Macmillan Publishing Company. New York, New York.

O'Brien, J.S., S. Okada, and D.L. Fillerup. 1971. "Tay-Sachs Disease: Prenatal Diagnosis." Science 172:61.

Panny, S.R., A.F. Scott, and J.A. Phillips. 1979. "Prenatal Diagnosis of Sickle Cell Disease by Restriction Endonuclease Analysis: Limitations and Advantages." American Journal of Human Genetics 31:58A.

Phillips, J.A., A.F. Scott, H.H. Kazazian, Jr., K.D. Smith, G. Stetton, and G.H. Thomas. 1979. "Prenatal Diagnosis of Hemoglobinopathies by Restriction Endonuclease Analysis: Pregnancies at Risk for Sickle Cell Anemia and S-O Arab Disease." Johns Hopkins Medical Journal 145:57.

Russell, J.G.B. 1973. Radiology in Obstetrics and Antenatal Pediatrics. Butterworths. London.

Saifer, A., L. Schneck, G. Perle, C. Balenti, and B.W. Volk. 1973. "Caveats of Antenatal Diagnosis of Tay-Sachs Disease." American Journal of Obstetrics and Gynecology 115:553.

Thatcher, V.S. ed. 1971. The New Webster Dictionary of the English Language. Consolidated Book Publishers. Chicago, Illinois.

Thiagarajan, S. 1974. "Gamegame II." Phi Delta Kappan 55:474.

Wyatt, P.R. and D.M. Cox. 1977. "Utilization of Electron Microscopy in the Prenatal Diagnosis of Genetic Disease." Human Heredity 27:22.

Appendix A

The Gene Scene

Game Pretest

1. Which of the following can be used for prenatal detection of genetic abnormalities?

   A. Amniocentesis
   B. Abortion
   C. Ultrasound
   D. Ultrasound and amniocentesis
   E. None of the above

2. The symbols AA, Aa and aa represent which of the following?

   A. The results of amniocentesis
   B. The chemical formula of an enzyme controlled by a gene
   C. Genotypes of different individuals
   D. None of the above

3. If a woman with the genetic constitution AA marries a man whose genetic constitution is Aa, what is the probability that they will have a child that carries the defective gene a?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

4. A woman whose genetic constitution is Aa is affected with the dominant trait, achondroplasia. If she marries a man whose genetic constitution is also Aa, what is the probability that they will have a child affected with achondroplasia?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

5. A woman who is a carrier for the recessive gene for PKU married a man who also is a carrier. Their first child was born with PKU. If this couple were to have a second child, what is the probability that it also will be affected?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

6. A man who is affected with the dominant genetic disease hypercholesterolemia marries a woman who is normal. If they have a normal child, what must be the genotype of the father?

   A. AA
   B. aa
   C. Aa
   D. aY
   E. None of the above

7. If a woman has the genetic constitution Aa and her husband is AY, what is the probability that they will have a child whose genetic constitution is aa (an affected female)?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

8. If a woman has the genetic constitution Aa and her husband is AY, What is the probability that they will have a child whose genetic constitution is aY (an affected male)?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

9. In what month of pregnancy is amniocentesis for prenatal detection of a genetic defect usually performed?

   A. Second month
   B. Fourth month
   C. Sixth month
   D. Eighth month
   E. Ninth month

10. How long does it ordinarily take to get the test results once amniocentesis is performed?

    A. 2-5 days
    B. 1 week
    C. 4-6 weeks
    D. 2-3 months

11. If a person has one normal gene and one defective gene for a recessive trait, he will...

    A. be completely normal.
    B. be affected by the recessive trait.
    C. appear normal, but he could pass the defective gene to his offspring.

12. If the genotype of a male is aY for a certain X-linked recessive trait, he would...

    A. be completely normal.
    B. be affected by the trait.
    C. appear normal, but he could pass the defective gene to his offspring.

13. If a man and a woman who are both normal for a certain genetic trait have a daughter affected with this genetic trait, the inheritance of the trait must be...

    A. dominant
    B. recessive
    C. X-linked
    D. cannot be determined

14. If a couple, both of whom have the genetic constitution Aa, expect a child, what is the probability that the child will have the genetic constitution aa?

    A. 0
    B. 1/4
    C. 1/2
    D. 3/4
    E. 1

15. A man who is a carrier for the recessive gene for cystic fibrosis marries a normal woman who does not carry the CF gene. What is the probability that they will have a child that is not a carrier?

    A. 0
    B. 1/4
    C. 1/2
    D. 3/4
    E. 1

16. Which of the following is not a function of a genetic counselor?

    A. Explain test results
    B. Explain the probability of having an affected child
    C. Explain how the genetic disease will affect the child
    D. Determine whether or not the couple being counseled should have children
    E. None of the above

17. If a person has one normal and one defective gene for a dominant trait, he will...

    A. be completely normal.
    B. be affected by the dominant trait.
    C. appear normal, but he could pass the defective gene to his offspring.

18. A child has the genotype Aa. If the father's genetic make-up is also Aa, what must be the genetic make-up of the mother?

    A. AA
    B. Aa
    C. aa
    D. cannot be determined

19. A woman whose genotype is Aa has a child with the genetic constitution AA. The father's genotype must be...

    A. AA
    B. Aa
    C. aa
    D. A or B -- it is not possible to determine which
    E. B or C -- it is not possible to determine which.

20. A man whose genotype is Aa is affected with a dominant trait. If he marries a woman whose genetic constitution is also Aa, and their first child is normal, what is the probability that their second child will also be normal?

    A. 0
    B. 1/16
    C. 1/4
    D. 3/4
    E. 1

The Gene Scene

Game Pretest Key

1. D
2. C
3. C
4. D
5. B
6. C
7. A
8. B
9. B
10. C
11. C
12. B
13. B
14. B
15. C
16. D
17. B
18. D
19. D
20. C

The Gene Scene

Game Post Test

1. In what month of pregnancy is amniocentesis for prenatal detection of a genetic defect usually performed?

   A. Second month
   B. Fourth month
   C. Sixth month
   D. Eighth month
   E. Ninth month

2. How long does it ordinarily take to get the test results once amniocentesis is performed?

   A. 2-5 days
   B. 1 week
   C. 4-6 weeks
   D. 2-3 months

3. If a couple, both of whom have the genetic constitution Aa, expect a child, what is the probability that the child will have the genetic constitution aa?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

4. If a woman has the genetic constitution Aa and her husband is AY, what is the probability that they will have a child whose genetic constitution is aY (an affected male)?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

5. If a woman has the genetic constitution Aa and her husband is AY, what is the probability that they will have a child whose genetic constitution is aa (an affected female)?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

6. A woman who is a carrier for the recessive gene for PKU married a man who also is a carrier. Their first child was born with PKU. If this couple were to have a second child, what is the probability that it also will be affected?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

7. A man who is affected with the dominant genetic disease hypercholesterolemia marries a woman who is normal. If they have a normal child, what must be the genotype of the father?

   A. AA
   B. aa
   C. Aa
   D. aY
   E. none of the above

8. A man who is a carrier for the recessive gene for cystic fibrosis marries a normal woman who does not carry the CF gene. What is the probability that they will have a child that is not a carrier?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

9. A woman whose genetic constitution is Aa is affected with the dominant trait achondroplasia. If she marries a man whose genetic constitution is also Aa, what is the probability that they will have a child affected with achondroplasia?

   A. 0
   B. 1/4
   C. 1/2
   D. 3/4
   E. 1

10. If a person has one normal gene and one defective gene for a recessive trait, he will...

    A. be completely normal
    B. be affected by the recessive trait
    C. appear normal, but he could pass the defective gene to his offspring

11. If a person has one normal and one defective gene for a dominant trait, he will...

    A. be completely normal
    B. be affected by the dominant trait
    C. appear normal, but he could pass the defective gene to his offspring.

12. If a man and a woman who are both normal for a certain genetic trait have a daughter affected with this genetic trait, the inheritance of the trait must be...

    A. dominant
    B. recessive
    C. X-linked
    D. cannot be determined

13. If the genotype of a male is aY for a certain X-linked recessive trait, he would...

    A. be completely normal
    B. be affected by the trait.
    C. appear normal, but he could pass the defective gene to his offspring.

14. A man whose genotype is Aa is affected with a dominant trait. If he marries a woman whose genetic constitution is also Aa, and their first child is normal, what is the probability that their second child will also be normal?

    A. 0
    B. 1/16
    C. 1/4
    D. 3/4
    E. 1

15. A woman whose genotype is Aa has a child with the genetic constitution AA. The father's genotype must be...

    A. AA
    B. Aa
    C. aa.
    D. A or B -- it is not possible to determine which
    E. B or C -- it is not possible to determine which

16. A child has the genotype Aa. If the father's genetic make-up is also Aa, what must be the genetic make-up of the mother?

    A. AA
    B. Aa
    C. aa
    D. cannot be determined

17. Which of the following can be used for prenatal detection of genetic abnormalities?

    A. Amniocentesis
    B. Abortion
    C. Ultrasound
    D. Ultrasound and amniocentesis
    E. None of the above

18. If a woman with the genetic constituion AA marries a man whose genetic constitution is Aa, what is the probability that they will have a child that carries the defective gene a?

    A. 0
    B. 1/4
    C. 1/2
    D. 3/4
    E. 1

19. Which of the following is not a function of a genetic counselor?

    A. Explain test results
    B. Explain the probability of having an affected child
    C. Explain how the genetic disease will affect the child
    D. Determine whether or not the couple being counseled should have children
    E. None of the above

20. The symbols AA, Aa and aa represent which of the following?

    A. The results of amniocentesis
    B. The chemical formula of an enzyme controlled by a gene
    C. Genotypes of different individuals
    D. None of the above

The Gene Scene

Game Post Test Key

1. B
2. C
3. B
4. B
5. A
6. B
7. C
8. C
9. D
10. C
11. B
12. B
13. B
14. C
15. D
16. D
17. D
18. C
19. D
20. C

Appendix B

Testing Data

Group One Fall Quarter 1982

Subject Number	Post test Score	Pretest Score	Difference
1	16	15	1
2	15	12	3
3	18	16	2
4	17	10	7
5	16	12	4
6	13	12	1
7	10	6	4
8	16	13	3
9	14	9	5
10	16	11	5
11	15	11	4
12	16	15	1
13	15	8	7
14	18	14	4
15	19	18	1
16	16	14	2
17	20	16	4
18	18	12	6
19	19	13	6
20	16	14	2
21	17	9	8
22	16	7	9
23	19	15	4
24	18	16	2
25	10	8	2
26	16	11	5
27	18	15	3
28	16	10	6
29	18	15	3
30	16	11	5

Subject Number	Post test Score	Pretest Score	Difference
31	20	17	3
32	19	15	4
Means	16.44	12.50	3.94
Sum of differences	---	---	126
Sum of the squared differences	---	---	632

Pairing Design Test

Group One Fall Quarter 1982

1. Null Hypothesis

   Mean of differences is equal to zero

   Mean of post test scores is equal to the mean of the pretest scores

2. Determination of $\underline{t}$ critical value

   Degrees of freedom = 31

   Two tailed test

   P = .05

   Therefore, the $\underline{t}$ critical value is equal to 2.04.

3. Determination of $\underline{t}$ experimental value

$$\underline{t} = \frac{\overline{X}_d - \mu_d}{S_{\overline{X}_d}} \qquad S_{\overline{X}_d} = \sqrt{S_d^2/n} \qquad S_d^2 = \frac{\Sigma d_i^2 - [(\Sigma d_i)^2/n]}{\text{degrees of freedom}}$$

$$S_d^2 = \frac{632 - [(126)^2/32]}{31} = 4.38$$

$$S_{\overline{X}_d} = \sqrt{4.38/32} = .37$$

$$\underline{t} = \frac{3.94 - 0}{.37} = 10.65$$

Testing Data

Group Two Winter Quarter 1982-83

Subject Number	Post test Score	Pretest Score	Difference
1	19	13	6
2	18	14	4
3	16	16	0
4	18	14	4
5	18	14	4
6	19	17	2
7	19	16	3
8	17	11	6
9	15	13	2
10	18	10	8
11	16	9	7
12	16	6	10
13	15	13	2
14	19	9	10
15	18	13	5
16	19	13	6
17	19	13	6
18	12	9	3
19	17	14	3
20	18	18	0
21	16	16	0
22	19	18	1
23	14	13	1
24	16	7	9
25	18	10	8
26	14	12	2
27	19	15	4
28	18	15	3
29	19	17	2
Means	17.21	13.03	4.17
Sum of differences	---	---	121
Sum of the squared differences	---	---	749

Pairing Design Test

Group Two Winter Quarter 1982-1983

1. Null Hypothesis

   Mean of differences is equal to zero

   Mean of post test scores is equal to the mean of the pretest scores

2. Determination of $\underline{t}$ critical value

   Degrees of Freedom = 28

   Two tailed test

   P = .05

   Therefore, the $\underline{t}$ critical value is equal to 2.05

3. Determination of $\underline{t}$ experimental value

$$\underline{t} = \frac{\overline{X}_d - \mu_d}{S_{\overline{X}_d}} \qquad S_{\overline{X}_d} = \sqrt{S_d^2/n} \qquad S_d^2 = \frac{\Sigma d_i^2 - [(\Sigma d_i)^2/n]}{\text{degrees of freedom}}$$

$$S_d^2 = \frac{749 - [(121)^2/29]}{28} = 8.72$$

$$S_{\overline{X}_d} = \sqrt{8.72/29} = .548$$

$$\underline{t} = \frac{4.17 - 0}{.548} = 7.61$$